
AC 2012-3733: AN ONLINE ENGINEERING STATICS PROBLEM SET SYSTEM

Dr. Franco Capaldi, Merrimack College

Franco Capaldi obtained his Ph.D. in mechanical engineering at MIT in 2005. He teaches at Merrimack College in Andover, Mass., and has previously taught at Drexel University in Philadelphia, Penn.

An Online Engineering Statics Problem Set System

Abstract

This paper details the development of a new on-line homework distribution and grading system for engineering statics. The system allows students to form solutions while allowing them to test hypotheses, interrogate the system, and sketch accompanying free body diagrams. The system grades the student's work and provides feedback while allowing the freedom to form a solution as the student sees fit. The software attempts to provide the student with a digital piece of paper on which to outline their solution. The instructor is provided with the student's grade, a copy of the student's solution, and performance metrics for the entire class. The system is currently being tested at Merrimack College in an Engineering Statics Course.

Introduction

Over the past decade, there has been a rapid improvement in "smart" computer tutoring systems. Computer systems are ideally suited to aid students who have difficulty visualizing structures. By allowing interaction, students may change the view angle to discern the three dimensional nature of the problem. In addition, the software may be used to guide a student through the solution process.

While students have different learning styles, and professors often have different teaching styles, it is becoming increasingly clear that effective assessment and immediate student feedback can produce beneficial results in the classroom [1]. Computer systems are ideally suited for such immediate feedback. They can also be used to present interactive case-based problems [2]. Systems have emerged which are capable of analyzing student response and providing targeted feedback to students when their response is incorrect. Systems such as ARCHIMEDES [3], Statics Tutor [4], Shaping Structures: Statics [5], BEST Statics [6], M-Model [7] and many others have emerged to provide students with modern computational learning tools [8] [9]. However, as noted by St. Clair and Baker [10], there remains room for improvement. None of these software solutions provides both an online distribution mechanism and a flexible entry system capable of handling a variety of problem types and vector notation.

An informal discussion with students who were currently using online homework systems revealed that students disliked using these systems for several reasons. Students find it difficult to ask the professor questions regarding the online solution and methodology. There is no record of effort involved or of partial progress made in the solution of the problem. Determining the exact format expected by the software is difficult. An informal discussion with professors using

the online software systems indicated that many professors found that scores for online homework did not correlated with student exam scores.

The software package described in this paper attempts to

- Create an online software package with automatic distribution and collection of homework assignments.
- A sophisticated entry system which allows for the entry of complex mathematical formulas.
- An automatic grading system which evaluates student entries.
- A feedback mechanism which identifies student errors and passes this information to both the student and the professor.

Desired Educational Outcomes

While this computer package was designed to be as flexible as possible and handle problems from a variety of fields, the statics solver was initially designed with the following limited set of learning objectives in mind:

1. Students should be able to represent physical quantities in vector notation and to use vector math to analyze a system. In fact, a good grasp of vector math and the relevant notation is necessary for all advanced engineering fields.
2. Students must be able to formulate appropriate free body diagrams when solving statics problems.
3. Students should be able to apply equilibrium equations in both two and three dimensions to determine unknown reaction forces, internal forces, or other unknown quantities.

With time and further revision of the software, this list will be expanded to include the calculation of centroids and moments of inertia.

Objective 1: Vectors and Notation

Traditional engineering statics courses begin with an introduction to vector math. However, students often find the notation confusing and sometimes arbitrary. Some software packages deal with the notation by carefully controlling solution entry. For example, a student might be able to type the numerical answer into a textbox which already has all of the proper formatting. A vector might be split into three separate text boxes for the \mathbf{i} , \mathbf{j} , and \mathbf{k} components respectively. In this software package, a completely flexible free form solution entry system was adopted. If a vector is given by $\mathbf{F} = 1\mathbf{i} + 2\mathbf{j} + 0\mathbf{k}$ [N], students may enter any of the following correct statements

$$\mathbf{F} = (1 * \mathbf{i} + 2 * \mathbf{j} + 0 * \mathbf{k})[N],$$

$$\mathbf{F} = (1 * \mathbf{i} + 2 * \mathbf{j})[N],$$

$$\mathbf{F} = (1 * \hat{\mathbf{e}}_x + 2 * \hat{\mathbf{e}}_y)[N],$$

$$\mathbf{F} = F_x \mathbf{i} + F_y \mathbf{j}$$

$$\mathbf{F} = \{1, 2, 0\} [N].$$

These are all evaluated in the same manner and all of these symbols are available in the software solution entry panel. By allowing free form entry, students are free to make mistakes. For example, an incorrect statement would be

$$F = (1 * \mathbf{i} + 2 * \mathbf{j} + 0 * \mathbf{k}) [N].$$

In this equation, the student has a scalar, F , on the left side of the equation (variable which is not bold) set equal to a vector on the right side. The software carefully analyzes the entry and notifies the user that the notation is incorrect. This ensures that notation is proper and that units are being assigned correctly. Let us look at the example problem given in Figure 1. The student is asked to find the component of the vector $\mathbf{F1}$ along the u-axis. When a student enters an answer, the system evaluates 1) whether the statement is correct 2) whether the statement provides the requested answer. Therefore, the following entries would be evaluated as shown in Table 1.

Table 1. Equation evaluation for the problem shown in Figure 1.

$F1_u = \mathbf{F1} \cdot \hat{\mathbf{e}}_u$	Correct, but not the answer
$F1_u = - \mathbf{F1} \cos(\theta + 45 [^\circ])$	Correct, but not the answer
$F1_u = -4.65 [N]$	Correct and the answer

Students are free to test their equations in variable form at various stages. In addition, the software retains all of the student entries which are then visible to the professor. This might be useful if a student wished to discuss the solution with the professor or ask a question about one of their entries. A professor might also use this record to gauge a student's thought process or to evaluate the effort a student is putting into a particular problem.

It is also worth noting that the software will gauge unit consistency. If the answer \mathbf{F} is in Newtons, then the following statement would be marked as correct

$$\mathbf{F} = 10 [kg] * 9.81 [m/s^2]$$

while

$$\mathbf{F} = 10 [N] * 9.81 [m/s^2]$$

would be flagged as having inappropriate units. If the professor wishes, the student may use the software as a calculator. Entering

$$10 [N] * 5 [m]$$

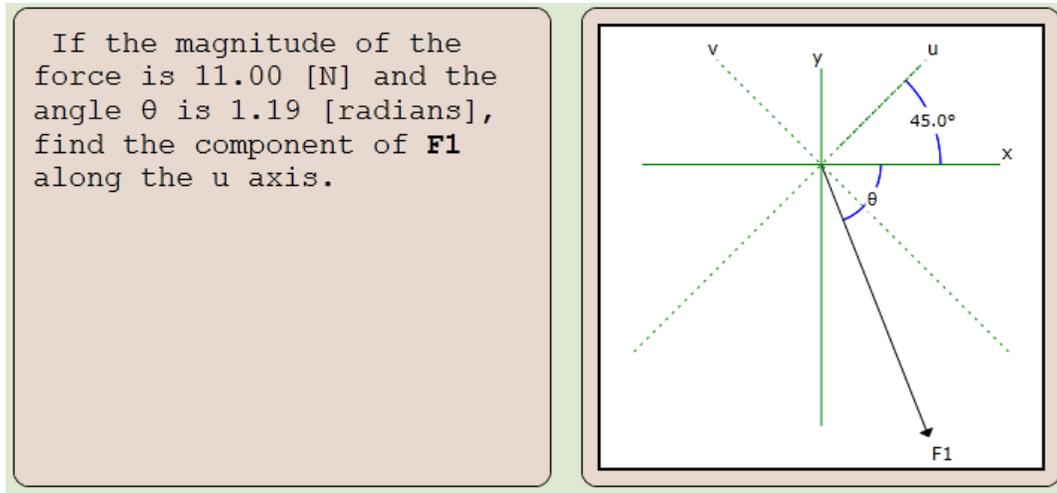
and pressing enter produces the result

50 [N m].

However, this option may be disabled if the professor wants to ensure the student is carrying out the unit conversions by hand.

Figure 1. (a) An example problem asking for the component of a vector along the direction given by \hat{e}_u . (b) The solution entry window.

a)



b)

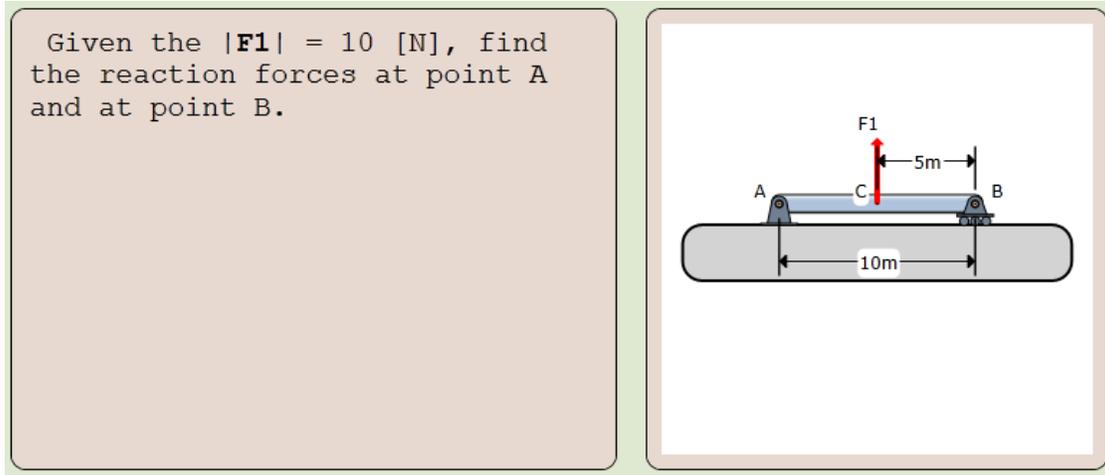


Objective 2: Free body diagrams.

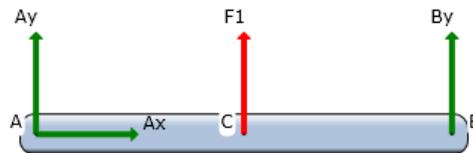
The ability to create valid free body diagrams is also integrated into the software. A free body diagram tool allows the user to select parts of the system and to place vector representations of the reaction forces, external forces, or internal loads where needed. For example, in Figure 2, the student is asked for the reaction forces at point A and B. The first step is to insert a free body diagram into the solution. The user selects the bar AB and hits the “create new free body diagram” button. The user then adds forces to the appropriate spots. The software checks to ensure the placement of reaction forces is appropriate. However, the software allows students as much flexibility as possible. For example, the student might enter two orthogonal reaction forces at the fixed support (one along the x and one along the y direction). They might choose to enter two non-orthogonal forces. Both are valid as long as the two reaction forces at A are not parallel. The software allows for such choices even if they are non-optimal. The reaction at B however, must be oriented along the positive y axis.

Figure 2. (a) Example problem asking for the reaction forces of a simply supported beam. (b) Student created free body diagram which is marked as correct.

a)



b)



Objective 3: Equilibrium equations

Once the student learns the basic concepts, the course quickly moves to complex structures whose solution requires more than one free body diagram and accompanying equilibrium equations. In these cases, the software allows for the entry of multiple free body diagrams and allows students to enter associated equilibrium equations. For example, in the example depicted in Figure 2, the student would enter the free body diagram shown in the figure and then would enter the components of the equilibrium equations. They could enter the equations in component form such that

$$\begin{aligned}\sum F_x &= Ax, \\ \sum F_y &= Ay + F_1 + By, \\ \sum M_A &= |r_{CA}| * F_1 + |r_{BA}| * By,\end{aligned}$$

or they might enter the vector equations

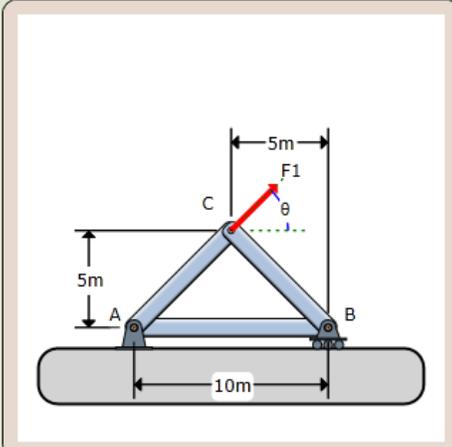
$$\sum \mathbf{F} = A_x * \mathbf{i} + A_y * \mathbf{j} + B_x * \mathbf{j} + \mathbf{F1},$$

$$\sum \mathbf{M}_A = \mathbf{r}_{CA} \times \mathbf{F1} + \mathbf{r}_{BA} \times (B_x * \mathbf{j}).$$

All of these are marked as correct. There is complete freedom to enter equations in any form for evaluation. This freedom allows advanced students to practice vector math, and intermediate students to use component notation. The software will alert students if a variable is missing from the equilibrium equation.

Larger truss problems such as the one shown in Figure 3 require multiple free body diagrams. The student would enter each free body diagram separately. Each new free body diagram is checked for consistency at any points which it shares with other free body diagrams. The names of reaction forces at common points must be identical. The vectors must be equal and opposite.

Figure 3. An example truss problem.

<p>Given the magnitude of the $\mathbf{F1}$ is 1.41 [N] and the angle θ is 0.79 [radians], find the reaction forces at point A and at point B.</p>	
---	---

Instructor Gradebook

Perhaps most critically, feedback is provided to the instructor via a gradebook. Each student's name appears along with a column for each class assignment. By clicking on the student's grade, the instructor is able to pull up the student's submitted solution. The solution contains all correct and incorrect entries made by the student and provides the means for the professor to gauge the student's performance beyond the numerical assigned grade.

Assessment

The first tests of this online system are being conducted in the Spring of the 2011-2012 academic year at Merrimack College. Feedback will be collected on student performance, ease of use, and the student perceptions of the system. Specifically, student feedback and performance will be evaluated through the following:

1. A mid-term survey will allow students to rate their experience using this software package.
2. A year-end survey will be conducted rating student experience.
3. Input via e-mails, casual conversation with individual students and in groups will be presented.
4. Actual student solutions submitted through the system will be shown which demonstrate the manner in which students interact with the software.
5. The instructor experiences with the software will also be recorded.

The results of this initial test will be presented at the ASEE conference in June of 2012.

Content Generation

Generation of content is extremely easy using this software package. In fact, the instructor simply creates a diagram of the problem and a list of questions. Creating a single static question requires only 5 minutes. However, generating a question which produces random diagrams for each student requires approximately 15 – 20 minutes.

Conclusion

In this work, we have assembled a software package capable of evaluating not only student answers, but student solutions. Initial feedback from students using this system, indicates that by allowing students to enter a solution step by step and in variable form, allows students to find their mistakes as they complete homework problems.

Readers interested in using the software for classroom instruction may contact the author for access to the online system.

References

- [1] P. Black and D. William, "Assessment and Classroom Learning," *Assessment in Education*, vol. 5, no. 1, pp. 7-73, 1998.
- [2] J. Kolodner, "Educational Implications of Analogy: A View from Case-Based Reasoning," *American Psychologist*, vol. 52, no. 1, pp. 1-10, 1997.
- [3] J. Dannenhoffer and J. Dannenhoffer, "Development of an on-line system to help students successfully solve statics problems," in *American Society for Engineering Education*, 2009.
- [4] DeVore, *Statics Tutor*, New Jersey: Prentice-Hall, 2000.
- [5] J. Iano, *Shaping Structures: Statics*, New York: John Wiley & Sons, 1998.
- [6] ISDC, "BEST Statics," [Online]. Available: web.umn.edu/~bestmech/preview.html.
- [7] E. Anderson, R. Taraban and S. Roberstson, "M-Model: A Mental Model based Online Homework Tool," *Journal of Online Engineering Education*, vol. 1, no. 2, 2010.
- [8] J. Lux and B. Davidson, "Guidelines for the development of computer-based instruction modules for science and engineering," *Mechanical and Aerospace Engineering*, 2003.
- [9] N. Hubing, D. Oglesby, T. Philpot, V. Yellamraju, R. Hall and R. Flori, "Interactive Learning Tools: Animating Statics," in *American Society for Engineering Education*, 2002.
- [10] S. W. St. Clair and N. Baker, "Pedagogy and Technology in Statics," in *American ociety for Engineering Education*, 2003.